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Using GIS to Detect Land Use Changes in the Salinas River Valley from 2001 and 2011

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Abstract:

The use of a Geographic Information System (GIS) to explore, analyze, and interpret our environment is a relatively new technology with exciting new advances emerging each day. GIS can be used along with satellite imagery to detect changes on Earth's surface (Delavar, 2015). With the human population growing rapidly, it has become very important to monitor when, where, and how we are changing the planet. Using the theory of land economics, coupled with land classification maps from 2001 and 2011, I will explain how cities are changing in the Salinas River Valley, a prime agricultural zone in central California. Are these cities expanding and are they consuming agricultural land? Are they becoming sprawled? There are questions that are vital to answer as we plan for the future of our cities and economies. Accommodating the growth of cities while preserving natural and agricultural land should be of central importance to local policymakers and leaders.

Introduction:

Classifying the various types of land use and land cover throughout the United States has been important to our understanding of the environment. Beginning in the 1960s, the United States Geological Survey (USGS) has been studying and mapping trends in land classification and use. USGS land use maps are created from 30-meter resolution satellite imagery. Each type of land on the Earth's surface has a unique set of reflectance properties that can be used to isolate and identify features (USGS, 2016). In other words, we can tell the difference between plants, buildings, water, and other geographic features, based on how much light they reflect in the various wavelength bands. Knowing how to manipulate these bands allows us to identify and classify features on the ground using satellite imagery.

“A geographic information system (GIS) lets us visualize, question, analyze, and interpret data to understand relationships, patterns, and trends. It is a software which links geographic information (where things are) with descriptive information (what things are)” (CSUMB, 2016). GIS allows us to clearly

show how geography affects us and how features and objects in our environment interact with one another. Measuring urban growth and using satellite images to classify land cover types is just one of many uses for GIS. After acquiring and analyzing data, a GIS can then be used to create maps and visualize data that can aid in making decisions and informing people of critical issues such as sprawl, which has become something that governments all around the world are concerned with because of its negative impacts on the productivity, infrastructure, and connectedness. When policymakers are making decisions about how to plan and manage an area, the use of GIS is enormously beneficial because it allows information to be presented in an easy-to-read format which includes spatial information and interactions.

There are many GIS computer programs available to use. One of the most popular, and the one I used for this research, is a software package called ArcGIS from the company ESRI. One program within the ArcGIS software package, ArcMap, allows users to input, visualize, and manipulate data, create new data, and produce color maps of the Earth (ESRI, 2016). ArcMap has many built-in tools and mathematical functions to manipulate and change data for better visualization and for creating new data. For example, starting with only data about terrain elevation, ArcMap tools can be used to derive slope, aspect, water drainage, creeks, and other new information based on the input elevation data.

A host of other GIS software packages exist as well. Some examples include QGIS, Geomedia, MapInfo Professional, Global Mapper, and Manifold GIS. Each of these programs centers on the core concept of geography, the idea that all things are connected but things closer together in space are more connected to each other. There are also a few GIS programs that we use every day without realizing we are using a GIS. Websites such as Google Maps use their own GIS to provide maps and directions to anywhere on the planet. The Federal Aviation Administration uses georeferenced maps for airplane navigation. Georeferenced maps contain information about where they are located in space and can be

displayed on an airplane's computer to help pilots navigate difficult approach paths to unfamiliar airports.

GIS is an enormously helpful tool in visualizing and analyzing our urban environment and can be coupled with theory to provide an explanation for why things change. In the case of urban growth, we turn to the theory of land economics. This theory argues that conversion of land from rural to urban use is a natural economic process (Brueckner, 1983). Because the agricultural land in the Salinas Valley is so rich and productive it retains a very high value for agriculture. As the population of a city increases, however, the price people are willing to pay for urban land rises. At some point the price people are willing to pay for urban land exceeds the value of agricultural land and the landowner will property to a developed to maximize profits. When this happens, land that was once undeveloped will become developed. When new lands are developed the pressure for space within the city is temporarily eased and the cost of rent decreases. The cycle will repeat when the population in an area increases and the cost of rent is driven up again.

Often in the United States we see sprawl in growing cities, a process in which new development occurs away from the existing city boundary rather than along the edges. Sprawl occurs when new development is detached from the rest of the developed land and a space of undeveloped land exists between the two developed areas (Wassmer, 2008). In the Salinas Valley, there is not a lot of room for sprawl. High value agricultural land can have the effect of buffering new development by resisting conversion and forcing developers to adhere more closely to the existing city boundaries. This results in cities that are dense and connected rather than sprawled and disjointed. Rather than spreading out into land that is disconnected from the city and building new roads and infrastructure that reaches back toward the city, it is more beneficial to append new development to the edges of a city and link in with the existing infrastructure.

In this research paper, I used data from the United States Geological Survey, the U.S. Census Bureau,

and the Multi-Resolution Land Characteristics Consortium (MRLC) to answer two questions: Is the Salinas Valley experiencing significant loss of agricultural land due to urban expansion, and are cities of the Salinas Valley becoming sprawled? The data that is available to the public through the above agencies allows for a detailed analysis of land uses, populations, number of households, and a comparison of satellite imagery from two dates in time. By comparing land use statistics from two points in time, I quantified the amount of land use change and the amount of developed land in Monterey County.

By understanding these processes of urban growth and carefully monitoring new development using GIS we can evaluate how and why our cities are expanding. This is important both for making decisions about the future and for evaluating the effectiveness of past policies. When city managers and developers create policies about how a city should grow, GIS can be used to look at past satellite imagery and measure changes over time. These changes can be compared to the way managers envisioned change and to see if their past decisions were effective. Because we can look back in time and visualize changes in the landscape it is much easier to understand and appreciate the complex processes involved.

During my service learning experience, I saw first-hand how important GIS information and mapping can be for local governments. I was involved in making maps depicting physical features of a city so planners could see where infrastructure exists and where it should be expanded. I also saw how GIS can benefit the everyday citizens of a city by making it easier for emergency responders to find an address and arrive quickly to someone in need. It cannot be overstated how important this new technology has already become. It is embedded in the way we see the world and make decisions. A firm grasp of geography is vital to making our cities a safer and more pleasant place for everyone who lives in them.

This paper will show that sprawl is not a major concern in the Salinas Valley. It will also explain why agricultural land, because of its high quality, is self-preserving. The loss of agricultural land in the Salinas Valley was minimal between 2001 and 2011. The biggest changes in development came within city

boundaries and resulted from increases in the intensity of already developed land. This is contrasted with an increase in the population of Monterey County. I will explain what this means and how to interpret this data through the lens of land economics.

Literature Review:

One of the many issues associated with growing cities is the phenomenon of urban sprawl. Urban sprawl occurs when new areas are developed which are not connected to the rest of the city they are associated with. Urban sprawl results in spaces of undeveloped land interspersed within and between areas of developed land. This is often seen as the process of growth growing haywire, out of control, and being poorly planned. But urban sprawl is not the result of a system gone awry (Brueckner, 1983). Rather, urban sprawl “is the result of an orderly market process” (Brueckner, 1983).

The concerns over urban sprawl have not been limited to the United States. For several decades, urban sprawl has been a prime concern among many European countries and their governments as well (Ferrara, 2010). Policies regarding urban growth, sprawl, and spread have been created but have proven to be largely ineffective for many Mediterranean cities. This should serve as a cautionary tale for city planners in the United States. Policies must be carefully thought out and meaningfully enforced. Without this enforcement, developers may construct new urban areas that are not connected to the main city and sprawl will occur.

Echoing this sentiment, Delavar and Mohammady (2015) note that sprawl is a concern for planners because:

The most important negative impacts of sprawl is that this kind of development causes the increase of car-dependency for transportation (Torrens and Alberti, 2000), the loss of agriculture, green spaces and natural land, increase in energy consumption, the need for more

infrastructure (Brueckner, 2001), and increase in infrastructure costs, longer travel times, increasing automobile trips and costs of travel and, therefore, greater environmental pollution, the degradation of periurban ecosystems (Johnson, 2001, Li et al, 2006).

Another reason for concern over how dense, or conversely how sprawled, a city has become is based on productivity. It has been suggested that cities with a denser urban core also have higher overall productivity as measured by metropolitan GDP per worker (Fallah, 2011). The implications are that planners who wish to create a city with a rich economy would want their city to be densely populated and avoid sprawl. It is also noted, however, that consideration must be given to individual choices of where people want to live, and forcing people to stay within a dense city is not the solution to preventing sprawl and improving productivity.

Sometimes cities may appear to be sprawled when they are not. That is, there may be large areas of undeveloped land within a city which appear to have been skipped over during the expansion of the city. Areas of undeveloped land in the middle of an otherwise developed area are referred to as dead land. These areas of dead land often cannot be developed due to clouded titles, tax delinquencies, or obsolete subdivision designs (Clark, 1965). This may apply to cities in the Salinas Valley where developers choose to build on former agricultural land at the outer edges of a city when apparently open land exists within the existing boundaries of the city. It is sometimes difficult to determine why land within a city is not developed without a great deal of research into the legal status of that land. It is often easier for a developer to avoid land tangled in legal issues and develop areas outside the city boundary which have a clear legal status.

One simple technique for measuring urban expansion is to examine the urban area of a city at two points in time and compare them to establish change. According to Jensen, this technique is shown to be

effective and is considered an acceptable way of quantifying urban expansion (Delavar, 2015). The abundance of satellite imagery provided by the USGS also makes this method reliable because of the consistently high quality data available to the public. By comparing land classification images from two different dates it is possible to quantify changes in land classification and the size of cities. Within GIS programs there are tools which can automate this process and yield a new map of specific places where change has occurred from one image to the next. These tools are continually being refined in each new release of the software.

The use of GIS to measure urban growth and sprawl is not a perfect science. There are many methods for measuring sprawl and none of them can completely describe the phenomenon with perfect accuracy. It is important to understand these limitations and acknowledge that much of urban planning comes down to experience and smart choices. As Bandyopadhyay notes, “measurement of sprawl from remote sensing data is still in its research domain” and “future researches to develop some more reliable sprawl measurement techniques are highly demanded” (2010). While we can create useful maps and data relating to the size and cities we study, we must still use human knowledge and ideas to interpret that data. GIS programs cannot make planning decisions for us, but they can be used to augment information that helps us make smarter choices about development.

Another important reason to monitor, measure, and control urban sprawl is continuity of peoples’ home and work lives. We’ve already seen that overall productivity is greater in cities with a dense urban population, and likewise people are happier when they do not have to commute too far. The distance that people are willing to commute, however, is further than expected. Orazem, Otto, and So write that people are generally willing to live up to an hour away from where they work, or an hour’s distance away via public transportation (Orazem, 2001). This explains why we see so many large, sprawling cities in the United States. Even though neighborhoods can be detached and spaced several miles apart, people are

generally willing to travel that distance.

There are a few characteristics of urban sprawl that we can use to identify the area it consumes compared to other forms of urban growth. In most of the world, the word sprawl carries a negative connotation and many people seem to know that sprawl is not something we want to experience in our cities. Clark writes, “sprawl, measured as a moment of time, is composed of areas of essentially urban character located at the urban fringe but which are scattered or strung out, or surrounded by, or adjacent to undeveloped sites or agricultural uses” (1965). In cities that are sprawled we see increased traffic, longer commute times, and higher stress level in people who drive further and further to work.

Echoing this sentiment, Wassmer points out that sprawl results in “separation of where people live from where they work, and a lack of functional open space” (2008). This separation is not only hard on the people who live in sprawled areas, it is also hard on the governments trying to regulate these areas and the infrastructure of the city. For example, if a new suburb is constructed several miles away from the urban core of a city, new fire and police stations will also have to be constructed to ensure emergency responders can reach the residents in time to help. New water lines, sewers, and electrical grids must be installed to provide the area with city services. This places a huge strain on city planners who must finance and coordinate infrastructure updates.

In addition to the infrastructure considerations, a wide range of factors determine when and where land is developed. Among those factors are land tenure, zoning directives, and housing prices (Colatoni, 2016). This means that policymakers and the voting public can have an important impact on which lands are developed and what they are developed for. Zoning directives are made by local governments, and it is important that local government officials understand the causes and effects of urban sprawl. Without this understanding they would not be able to create policies which lead to a densely populated and continuously developed city rather than a disjointed, sprawled, and stressed city.

Regardless of where development occurs, we can see interesting things happening at the urban-rural fringe, where cities and agricultural areas interface and adjoin each other. Because people are increasingly concerned with the quality of foods they eat and how far away the food has come from, there is a corresponding increase in the amount of specialty crops on farmland that is located closer to urban centers and farmers' markets (Delbecq, 2010). We can see this happening every day in Monterey County when we visit any of the fresh produce markets in the area. Crops that sell well at markets are grown on land closer to the city because the travel distance from farm to table is relatively short, which people value. By using land closest to the city to grow specialty crops, farmers further increase the value of agricultural land located along the urban-rural fringe because residents of the city are willing to pay more for the specialty crops grown there.

The concern over local produce has roots going back to the early days of the automobile. We are now able to grow food in one place and ship it to consumers thousands of miles away. The automobile changed the way people eat, and it changed the way we build cities. Kenworthy reminds us that relying on cars to get us around is part of the reason sprawl is an issue in the United States (Dieleman, 2004). Cities can expand and sprawl because people have cars to drive themselves great distances between developed spaces. Awareness of sprawl has been growing among citizens and planners in recent decades. Although cars make sprawl possible, people are realizing that cars are not the answer to everything. Much the same way people want to eat foods grown close to them, they also want a sense of connectedness in their neighborhoods. This new awareness may help fight sprawl in the future, but it cannot help areas which are already sprawled or make up for poor planning in future development.

It is also important to note that there is more concern over the sizes of cities than there is with their shape. A city can grow in any direction or shape if it remains dense and compact. "Giant cities are often considered dysfunctional—too congested, unserviceable, fiscal drains on national treasuries and

unmanageable from a governance standpoint” (Cervero, 2001). Some of the cities in the Salinas Valley take on shapes that are not the normal circular or square shape that we often expect to see in the United States. But those odd shapes do not matter. What matters more is whether any of the cities have reached a certain critical size at which they become undesirable to live in.

Theory:

Theory of land economics was originally developed by Brueckner in the early 1980s and has since been modified by themselves and others as we learn more about how land use can change over time. Brueckner describes how economics can drive land uses and how those uses will change over time based on the profit that can be made from a piece of land for various purposes. They make the argument that land use changes are the result of normal economics and urban sprawl should not be seen as cancerous growth that mindlessly eats up valuable agricultural land. There is a predictable and reliable way to assess land use change by evaluating where the most profit can be made from a piece of land.

As cities increase in population the price people will pay for living space, known as rent, also increases. In addition to the urban rent prices there is also an agricultural rent price, which is the amount of money that can be made from products grown on a piece of land. Land with higher quality soil which can grow more agricultural products will be more valuable than agricultural land which cannot support as many or as healthy of an agricultural product (Brueckner, 1983).

There comes a point when the price of rural rent exceeds the price of agricultural rent, a point at which more profit can be made from selling a piece of farmland to a developer than from continuing to farm the land. When this tipping point comes, there is a conversion of land from rural to urban use. Because high quality agricultural land has a higher rent price it will be highly resistant to sale and conversion to urban use. The first lands that will be converted to urban use are the lands with the lowest agricultural quality. This follows a predictable pattern of economics and preserves the highest quality agricultural

land for continued farming (Brueckner, 1983).

Based on this model we should not consider urban expansion to be an uncontrollable blight. We should see it as something that is predictable and is in the best economic interest of all involved. This is an interesting viewpoint because we so often consider urban growth and sprawl as a process which destroys the landscape and leaves certain areas alienated or segregated from the rest of the city. People who make that argument are not accounting for farm owners who make the deliberate decision to sell their land for urban development to maximize profit.

It is also possible that high-value agricultural land around the cities of the Salinas Valley is serving as a buffer against their outward expansion (Colatoni, 2016). While the idea that high quality agricultural land can hamper the outward expansion of a city is not directly related to the theory of land economics, it is easy to see how they complement each other. Because the owners of high quality land are more inclined to continue farming their land to generate income from crops, that land naturally will hamper expansion of a city. Land will be developed for urban use if the owner profits more from growing crops than from selling the land.

Cities of the Salinas Valley are generally surrounded by farm lands owned by agricultural companies. There is not an easy direction the cities can grow where they will not encounter stiff resistance from high quality farmland. The easiest solution, it would seem, is for developers to find a way of fitting more people into the same area of a city. While the theory of land economics does not directly discuss housing density, it does suggest that new development of land will ease pressure on a housing market. We can conclude the opposite must be true and farmland that is resistant to change will drive up housing density. If it is impossible for a city to grow outward to accommodate more housing units and more people, then more people must find a way to live in the same amount of space. This can happen when a city grows upward rather than outward. Growing upward leads to more housing units, and more people, in the same

area of land.

Methodology:

There are many sources for satellite imagery, land use maps, and population data. The simplest site for downloading satellite imagery is the USGS Global Visualization Viewer (GloVis). This site allows users to define search criteria, select a satellite source, and view imagery on a map before downloading the raw data. Users can browse and download data for free after creating a user account with the USGS. Sources available through GloVis include Landsat TM/ETM+, Aster, MODIS, Sentinel, and TerraLook, all of which are remotely sensed data sets used to detect and research specific aspects of Earth. Landsat 7 and 8 satellite images were downloaded and used to compare visual changes in Monterey County during my research. The Landsat satellites each cover the Earth every 16 days and can easily be used to evaluate changes. The two satellites collect roughly the same type of data with only minor differences between them.

Land classification maps were acquired from the Multi-Resolution Land Characteristics Consortium website. These maps are based on USGS satellite imagery and classify the entire United States based on land classification. The maps are available for the years 2001 and 2011. Of particular interest are lands classified as cultivated crops (agricultural) and as developed. In the MRLC maps, developed land is divided into four categories based on how intense the development is. The categories include open spaces, and low-, medium-, and high-intensity development (MRLC, 2016). These categories can be used to determine whether land was newly developed in the time between 2001 and 2011 and whether land increased in development intensity. Lands that were newly developed between 2001 and 2011 can also be evaluated to determine what the original land use was in 2001. By knowing what the land use category was in 2001 it's possible to evaluate whether agricultural lands were converted to urban use.

It was also important to find information about population and households within Monterey County.

For this information I turned to the U.S. Census Bureau. The Census Bureau maintains an online database of census data which is also free to access for the public. The data reflects census tracts and blocks, populations, households, income levels, and various other demographics about people living in the area. The Census Bureau conducts a major census every ten years, which closely aligns with the MRLC data. The census data used is from the 2000 and 2010 census, the two most recent datasets available. Because the MRLC data and the census data are only offset from each other by one year it's possible to closely compare the two.

Most of the data available for download comes in several formats. The format needed will vary based on the type of research and the computer programs being used to analyze the data. For this project, all USGS and MRLC data was downloaded in high resolution GeoTIFF format. GeoTIFFs are Tagged Image File Format images which contain geographic information. Using the geographic information in the image, ArcMap can correctly place the image where it belongs in space. Because the location of the image is known it is possible to accurately overlay the position of other features such as roads, rivers, and cities, and make sure they are in the correct alignment with one another. Because I am directly comparing data from two different years it is very important they are correctly located on the map or else errors will occur during analysis.

The downloaded data was added to a workspace in ArcMap. The first step in using such large pieces of data, such as the MRLC rasters which cover the entire United States, is to trim them to a specific study area. This not only reduces the sizes of the files, it also saves time by cutting out parts of the map we are not interested in, and limits computations to a smaller area. To crop the data I used a polygon representing the boundary of Monterey County and cropped the MRLC rasters to this polygon using the clip tool located in the raster processing toolbox of ArcMap. This tool automates the process of creating a new MRLC raster image which contains only the data that falls within the boundaries of the Monterey

County polygon.

I then reclassified the cropped MRLC rasters to eliminate some land classification categories which are not present in Monterey County or that were not important to this research. For this step, I focused on developed classifications to create a new raster only showing areas which are categorized as being developed in some way. Then, using the combine tool in conjunction with the cropped MRLC land classification data, I created another new raster showing the places where land uses changed between the 2001 and the 2011 land classification datasets. The combine tool also creates a table listing the original land classification of each pixel, whether they changed in classification, and what classification they changed to. This information makes it possible to map areas where land classifications have changed from one type to another. All the land classification data used is based on Landsat imagery with a 30-meter pixel size, which allowed me to quantify the land classification changes in terms of the area they cover.

After the table for land use types and their changes was computed in ArcMap, I chose to manually edit the data tables to add important information. The MRLC data for land classification is coded by numbers, but a descriptive label was also necessary. To add these labels, I exported the attribute table for the MRLC maps to Microsoft Excel and added information to clarify what each number represented. I also added fields in the Excel file to compute the area of each land classification type. This was done with a simple mathematical equation which multiplies the number of pixels for each land classification category by the size of the pixels, which yields area. The area was first calculated in square meters, and an additional equation was required to convert the units to acres. Once the areas were calculated I used a third equation to obtain the percentage of change from 2001 to 2011.

Land Class	2001 Count	2011 Count	2001 Area (m2)	2011 Area (m2)	2001 Area (acre)	2011 Area (acre)	Change (acre)	Change % (acre)
11 - Open Water	38835.00	38375.00	34951500.00	34537500.00	8636.69	8534.39	-102.30	-1.18
21 - Developed, Open Space	531944.00	527243.00	478749600.00	474518700.00	118301.42	117255.94	-1045.48	-0.88
22 - Developed, Low Intensity	124345.00	122760.00	111910500.00	110484000.00	27653.64	27301.15	-352.50	-1.27
23 - Developed, Medium Intensity	85971.00	93533.00	77373900.00	84179700.00	19119.48	20801.22	1681.75	8.80
24 - Developed, High Intensity	15737.00	18579.00	14163300.00	16721100.00	3499.82	4131.87	632.05	18.06
31 - Barren Land	144232.00	150919.00	129808800.00	135827100.00	32076.40	33563.56	1487.15	4.64
41 - Deciduous Forest	800.00	787.00	720000.00	708300.00	177.92	175.02	-2.89	-1.63
42 - Evergreen Forest	1250608.00	1250139.00	1125547200.00	1125125100.00	278128.34	278024.04	-104.30	-0.04
43 - Mixed Forest	877887.00	867319.00	790098300.00	780587100.00	195237.24	192886.98	-2350.27	-1.20
52 - Shrub/Scrub	2779140.00	2774055.00	2501226000.00	2496649500.00	618065.45	616934.57	-1130.88	-0.18
71 - Grassland/Herbaceous	2549035.00	2534496.00	2294131500.00	2281046400.00	566891.36	563657.97	-3233.39	-0.57
81 - Pasture/Hay	91013.00	97447.00	81911700.00	87702300.00	20240.79	21671.68	1430.89	7.07
82 - Cultivated Crops	933111.00	947591.00	839799900.00	852831900.00	207518.75	210739.03	3220.27	1.55
90 - Woody Wetlands	73516.00	72579.00	66164400.00	65321100.00	16349.55	16141.17	-208.38	-1.27
95 - Emergent Herbaceous	42283.00	42635.00	38054700.00	38371500.00	9403.51	9481.79	78.28	0.83

Table 1. A summary of land classification type and counts of their area in square meters and in acres.

ArcMap allows data on a map to be color coded to represent different values or a range of values. Using values that are known to represent developed areas and changes in the intensity of development, it's possible to create a map which visually shows where development has occurred. These areas can also be displayed with city boundaries, roads, rivers, and census data to create a complete picture of where development is happening. I generated maps which show areas classified as being developed and maps showing areas that changed in development status. These maps make it easy to see where development is taking place and they show how land is being converted in a visual format.

Results:

The results table of the combine command in ArcMap shows whether each pixel has changed in land classification from 2001 to 2011. The table lists the original classification, the new classification, and how many pixels have changed. In 2001, there was a total of 168,574 acres of developed land within Monterey County. This number increased slightly to 169,490 acres of developed land in 2011. The change in total developed land within Monterey County increased by 915 acres in the period between 2001 and 2011, an increase of 0.54%. For these calculations developed land is land classified as having any type of development according to the MRLC data.

The amount of cultivated cropland in Monterey County shows a slightly larger increase from 2001 to 2011. In 2001 the total area of cultivated cropland within Monterey County was 207,519 acres. The overall increase in cultivated cropland was 3,220 acres, an increase of 1.55%. These results show that land was converted to agricultural use at a higher rate than land was being newly developed in Monterey County. Table 2 reflects these numbers and shows that agricultural and, according to the MRLC, grew at a faster rate than developed land.

The relationships between land classification changes becomes more interesting after comparing them to population changes during the same period. In Monterey County the human population was 407,065 in 2001. The Monterey County population increased by 14,278 people over the next ten years to reach a total of 421,343 in 2011, an increase of 3.51% (U.S. Census Bureau). As you can see, the population in Monterey County increased by a higher percentage than newly developed land from 2001 to 2011. The Census Bureau also reports the total number of households in Monterey County. The total number of housing units in Monterey County remained the same from the 2000 census to the 2010 census at 139,048 total housing units (U.S. Census Bureau).

2001 Developed (acre)	2011 Developed (acre)	Developed Changed (acre)	Developed Changed %
168574.36	169490.18	915.82	0.54

2001 Cultivated (acre)	2011 Cultivated (acre)	Cultivated Change (acre)	Cultivated Change %
207518.75	210739.03	3220.27	1.55

2001 MoCo Population	2011 MoCo Population	MoCo Pop. Change	MoCo Pop. Change %
407065.00	421343.00	14278.00	3.51

Table 2. Summary of developed land, cultivated cropland, and population in Monterey County. The table shows changes in the amount of land classified in each category alongside population data from the U.S. Census Bureau.

After examining a map of where land classifications either changed from undeveloped to newly developed, or where land development increased in intensity, it becomes clear that most increases in development have occurred within the existing boundaries of cities in Monterey County. In other words, new development was contained to areas that were already developed in some way and new development did not occur in agricultural areas. This is important to note because it indicates that there is something preventing development of new land. According to our theory, the factor preventing development is the high value of agricultural land. The farmlands of the Salinas Valley are resistant to conversion to urban use because of their high value to farmers and landowners.

Analysis:

When looking at the results through the lens of urban sprawl, urban expansion, infrastructure management, and planning regulations, things look promising for Monterey County. Although the county population increased by nearly 15,000 people over a decade, the amount of agricultural land in the county remained relatively stable. The increase in developed land within existing city boundaries indicates that space for new residents of Monterey County was most likely created by building additional housing, or more dense housing, in areas that were already intended for development. Rather than expanding outward or developing sprawled areas that are disjointed from the larger city and consume agricultural land, development was limited to areas that could not have been used for agriculture as of 2001.

It is possible that the high quality of agricultural lands surrounding the cities of Salinas Valley is acting as a buffer to development by making farmers unwilling to sell land. This seems a likely scenario given that agricultural products of the Salinas Valley are shipped and sold all over the world. The agricultural land in the Salinas Valley has very high soil quality and regularly sees good crop harvests. With a regular income coming from crops, land owners want to keep their land for rural use. There is no reason to develop land that is already making the owner a good profit.

The theory of land economics explains why agricultural land in the Salinas Valley is so resistant to development. There will come a point, the theory predicts, that the population will increase to a point that rural land is converted to urban use, but that point does not seem to have been reached in the period between 2001 and 2011. It may be the case that urban rents were rising during that period but did not exceed rural rent.

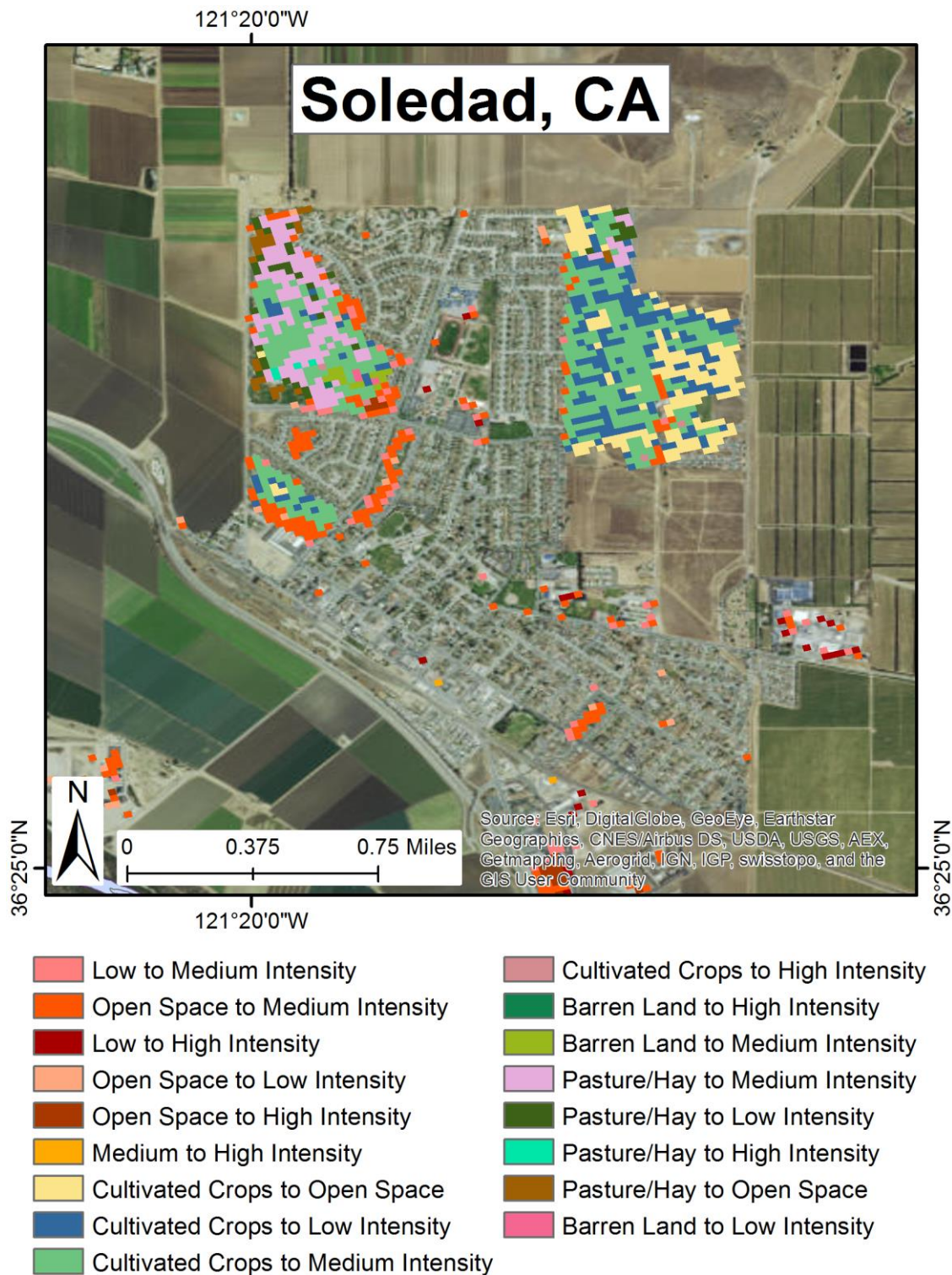


Figure 1. Areas where land classification changed from 2001 to 2011 in Soledad, CA. Areas that changed from undeveloped land to some category of development are shown. Areas of new development are clearly visible on the north side of town.

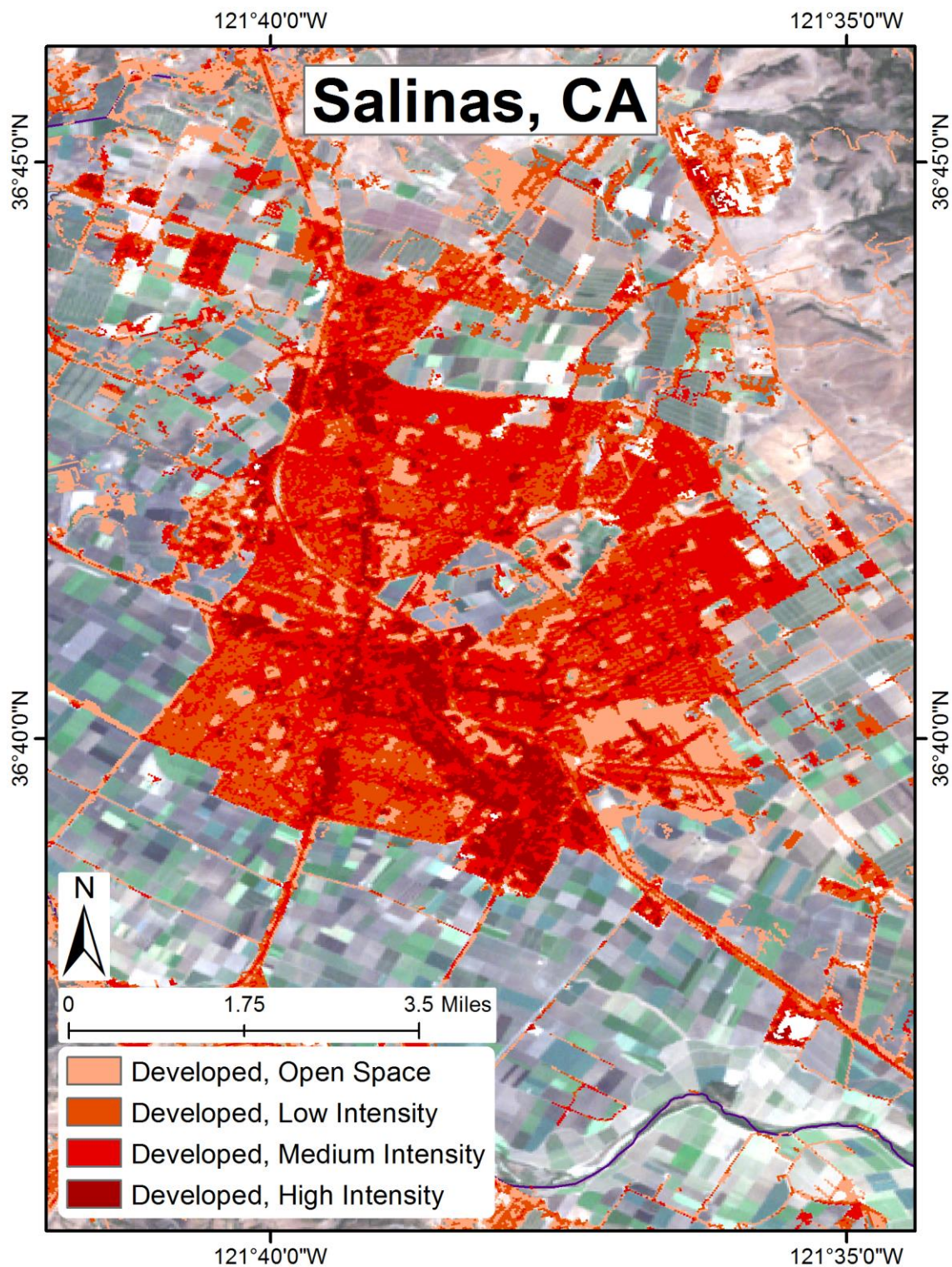


Figure 2. Developed land around Salinas, CA. This map shows the areas that are classified as being developed according to the MRLC data. The areas in darker red indicate higher intensity of development.

If the Census Bureau data is accurate, then no new homes were built in Monterey County between 2000 and 2010. While these dates do not exactly match the dates of the land classification maps, they are aligned closely enough to be very useful. It is not very likely that the number of households remained completely unchanged over a ten-year time span and this seems like an error in the census data. Because of this, though, it is difficult to evaluate housing density in Monterey County. We know the population increased, and we know there was a slight increase in developed land. What we do not know for sure is whether there was an increase in housing units. If there was no increase in housing units, then cities are in fact becoming denser by virtue of having more people in the same number of homes.

There is also no evidence of sprawl occurring in the Salinas Valley. In fact, there is very little outward growth of cities at all. The areas that we see having a change in development classification are contained within other existing developed areas. With no outward expansion of cities there is also no development in areas disconnected from the cities. Increases in development intensity were much more common than conversion of land for new development. This does not mean the balance of urban and rural rents is remaining the same. It's possible that urban rents are increasing and will soon exceed rural rent prices. This is not something that was measured by this research and I cannot say whether new development may occur soon. If development does occur, it is likely to be small areas attached to an existing city and not an isolated area.

Conclusion:

After examining land classification changes in Monterey County, it is evident that urban expansion, sprawl, and the loss of prime agricultural land was not a significant issue in the period between 2001 and 2011. Based on the factors of how much land is available for urban use, population increase, and housing availability, it appears that cities in the Salinas Valley are not growing outward at a significant rate. There appears to be an increase in the density of people within cities. Because the increase in population rose

much more quickly than the amount of developed land, it seems most likely this is the case.

The most important conclusion that can be made from this research is that agricultural lands are not being lost to urban development at a significant rate. The preservation of agricultural land should be a prime concern for policymakers and planners in Monterey County. The loss of such fertile lands to development would have long-lasting impacts on the local economy and the nation. The reasons why agricultural land is being preserved are complex and interrelated, and how they influence land use must be understood if we wish to make the right planning decisions. For now, though, we can be assured that highly productive agricultural lands seem to be resisting conversion to urban use.

The evidence also points to the conclusion that cities in the Salinas Valley are not sprawling, and will not become sprawling soon. They are of a relatively small size and do not appear to be growing outwardly. There has been an increase in development intensity within city boundaries, and there has been some expansion into farmlands by cities of the southern Salinas Valley, but overall the impact on farmland has been minimal. As populations continue to increase in Monterey County it is unknown when the time will come that cities must expand outward to accommodate new residents.

Proper planning and guidance from local officials can prevent cities from becoming sprawled or consuming too much valuable land when the time comes that they must expand. It seems inevitable, however, that housing rent will increase to the point that land owners will sell their property to developers. We know, based on the theory of Brueckner and Fansler, that this point will come if the population continues to increase. An increasing population will lead to higher rent prices while the profits made from agricultural land remain stable.

It is difficult to draw conclusions about housing density based on the available U.S. Census Bureau data. It's very unlikely the number of housing units remained the same over the ten-year period from 2001 to 2011. We can see from land classification maps that new areas in Soledad were developed during

that time, and satellite imagery shows the new development to be housing. It would seem, based on the land classification data, the number of housing units in Monterey County must have increased. It also seems the population density must have increased because there was no significant increase in the total size of cities in the Salinas Valley.

Recommendations:

There is much more research that can be done to build upon this paper. More thorough research into the lives of people who are moving into the Salinas Valley would provide valuable insight into how and why Monterey County cities are changing. The focus of this paper is quantitative, centered on land use changes. A qualitative analysis of agricultural lands, new development, and quality of life in Monterey County would also be useful. Other data sources could be incorporated into research on this topic to show how a wide variety of factors can influence land use changes.

Research looking at demographics and specific social groups in Monterey County could also add to the understanding of what drives land use changes. If there are mostly families moving to the area then we would expect to see an increase in development of single family homes. If unmarried people are moving to the area, we might expect to see an increase in apartments or condominiums. This type of analysis would help to focus on specific groups and identify what type of development should be expected.

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